Influence of Thrust, Torque Responsible for Delamination in drilling of Glass Fabric – Epoxy / Rigid polyurethane foam sandwich hybrid composite

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***Abstract*— Glass fabric sandwich composites are potentially growing materials which satisfies the low strength to weight fraction, thermal conductivity, high strength and long operational lifetime required for key engineering applications especially in the field of Mechanical and Aerospace structures. With their wide range of application, their manufacturing and machinability characteristics are interesting to investigate. Drilling is one of the prime manufacturing processes used in assembly lines of components for fastening and joining two components. In this study, Glass Fabric – Epoxy / Rigid polyurethane foam sandwich hybrid composite is drilled in Arix VMC 100 CNC drilling machine using High Speed Steel (HSS) drill bit of three different diameters of 6 mm, 8 mm and 10 mm. A L_9 orthogonal array is setup to investigate the result. Two main parameters that contribute to delamination are thrust and torque. Thus in this investigation, thrust and torque responsible for the effect of delamination and hole quality is studied experimentally. Scanning Electron Microscope (SEM) images are taken for the drilled hole laminate to support the result.**

***Index Terms*—manufacturing, Glass Fabric – Epoxy / Rigid polyurethane foam sandwich hybrid composite, HSS, thrust, torque.**

I. INTRODUCTION

The use, in primary structures, of fiber-reinforced plastics has increased in the last decades due to their unique properties. Advantages are related with their low weight, high strength, long operational lifetime and stiffness. Although the development of these materials have been mostly related with aerospace and aeronautical applications, recent years have seen the spread of their use in many other industries, like automotive, where high production rates are required. The use of composite laminates in dynamic structures had enabled a considerable weight reduction and, consequently, an improvement in their characteristics. Although composite components are produced to near net shape, machining is often needed, as it turns out necessary to fulfill requirements related with tolerances or assembly needs. Machining operations in composites can be carried out using conventional machinery with adaptations. Among machining processes, drilling is one of the most frequently used to make holes for screws, rivets and bolts. However, drilling is a complex process, which is characterized by the existence of extrusion by the drill chisel edge and cut by the rotating cutting lips. As composites are neither homogeneous nor isotropic, drilling raises specific problems that can be related with subsequent damage in the region around the hole. The most frequent defects caused by drilling are delamination, fiber pull-out, inter laminar cracking or thermal damages. These defects can affect not only the load carrying capacity of laminated parts but also the reliability. Rapid tool wear, as a result of material abrasiveness, can be an important factor in damage occurrence too and increases the need of frequent tool changes that affects the production cycle. When drilling of a composite part is considered, results are more dependent on fiber nature than on matrix material. Drills are widely used in industry to produce holes rapidly and economically. In fact, the chisel edge of the drill point pushes aside the material at the center as it penetrates into the hole. High Speed Steel drill bit has been used for drilling of composite materials. Cutting variables in drilling process (feed and speed) have great influence on the delamination factor and hence on the quality of the machined holes. Low feeds in some cases improve the surface roughness due to the reduction of thrust force. The drilling of composite laminates generates several kinds of damage, which are described at the macro level (delaminated area) and at the micro level (cracks, fiber-matrix debonding, etc.). Delamination is the most evident damage that can be generated during the drilling of a laminate. This kind of damage is classified as peel-up delamination at the twist drill entrance and push-down delamination at the twist drill exit. Pushdown delamination is mainly affected by the feed rate, by the presence of support beneath the specimen, and by the drill temperature. Stress concentration, delamination and micro cracking associated with drilled holes significantly reduce the composites' performance. An experimental study has been performed to analyze the influence of drilling parameters on delamination factor of Glass fabric/ Polypropylene matrix Composite. High-speed cutting (HSC) plays an important role in machining process in order to increase productivity as well as material removal rate and thus decreasing machining cost. An attempt has been made in this work to analyze the main and interaction effects of process parameters, namely, cutting speed and feed rate on delamination factor.

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II. EXPERIMENTAL SETUP

A. Fabrication of Glass Fabric – Epoxy / Rigid polyurethane foam sandwich hybrid composite

It is an extremely effective method of producing stiff, light and cheap structures in FRP, when used in the right application in the right manner. Sandwich structures are generally used to improve the flexural rigidity performance in terms of cost, or weight of a panel or a beam. The foam is coated with an adhesive material on top of which is placed skin material. Bonding between the skin-epoxy and epoxy-core results in the stiff structure. Sandwich construction can also be used for complex-shaped component by pre measuring the core material to shape. One very good example is the use of honeycomb as the core material for the many forms of aerofoil shape. Where sandwich structures are being used in place of similar components manufactured from conventional materials, the task of design in composites is simplified by having a standard of performance to meet or improve on. The aluminium sheets and the glass fibers were cut to the dimensions of 110X60cm. The aluminium sheet was placed on the die and was sprayed with Silicone lubricant to facilitate the ease in removal of the composite after manufacture. Initially one layer of glass fabric is placed on the aluminium sheet whose surface is covered with the lubricant. One layer of resin coating was applied on the layer of glass fabric over the glass fiber sheet rigid polyurethane foam was placed. Another two-layered glass fabric epoxy skin was bonded to the other face of the foam. This is done so in order to obtain an approximate 33 mm thick sandwich composite. Fig. 3 shows the schematic of Compression Molding machine.

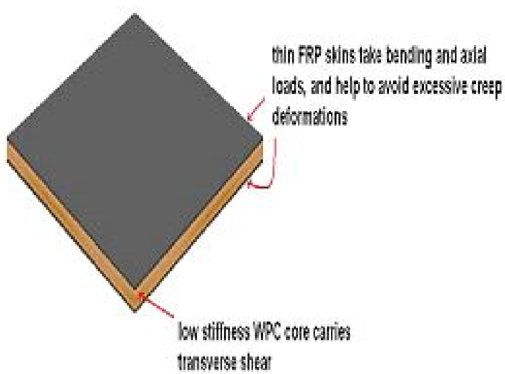

Figure 1. Hybrid Composite

B. Properties of Sandwich composite specimen

Properties of E Glass

TABLE I
PROPERTIES OF E GLASS

Typical Compositions of Glass Fibers (in wt%)	E glass:	Tensile strength of E-glass fiber (GPa)	Compressive strength (GPa)	The Young's Modulus is (GPa)
SiO_2	54.5	3.4	4.2	70-80
Al_2O_3	14.5			
CaO	17			
MgO	4.5			
B_2O_3	8.5			
Na_2O	0.5			

Properties of Resin

TABLE II
PROPERTIES OF RESIN

HY 951	Epoxy LY 556/
T_g, (Celsius)	120
Strength, (MPa)	140.7
Flexural properties (room temperature)	
Strength (% retained)	55
Moisture gain, %	3
Modulus, (GPa)	2
Modulus (% retained)	64.5

C. Experimentation

A schematic diagram of the experimental specimen is shown in Fig. 2. The holes were drilled in the Glass Fabric – Epoxy / Rigid polyurethane foam sandwich hybrid composite specimen in DENFORD NOVAMILL using high speed steel (HSS) drill bit of 6, 8. and 10 mm diameter. The proper clamping system was used for fixing composite laminates in machining center and two composite boards were simultaneously drilled. The drilled holes were analyzed under Tool Maker's microscope (Mitutoyo) of 1mm resolution with 30x magnification was employed to measure the delamination damage at the entrance of the holes. The spindle speed was varied from 1000 to 3000 rpm and the feed rate was 50, 75 and 100 mm/min. The SEM images of the holes that gave delamination factor closer to unity and which deviated to a large extent were taken and studied.

Figure 2. Arix VMC 100 CNC Drilling Machine

Figure 3.Compression Molding machine

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IV. RESULTS AND DISCUSSIONS

A. Delamination

After drilling, it is necessary to define criteria for the comparison of the delamination caused by different drilling parameters, even though they can only be applied to composites with the same stacking sequence and reinforcement fiber in nature and volume fraction. Several ratios were established for damage evaluation. One of them is delamination Factor (Fd), a ratio between the maximum delaminated diameter (Dmax) and hole nominal diameter (D).

$$\mathbf{Fd} = \mathbf{D}_{max}/\mathbf{D}$$

in which *D*max being the maximum diameter of the delamination zone and *D* is the hole diameter. Fig. 3 shows the schematic view of a Tool Maker's microscope with which delamination was measured. Cutting speed is considered as having a major role in the indentation over the uncut thickness of the material, resulting in higher influence on delamination onset. Compared to cutting speed, the effect of feed rate is slight. Fig 4 shows the effect of cutting speed and feed on delamination factor. In general, it can be noticed that the delamination factor increases as the feed is elevated but decreases as the spindle speed is increased.

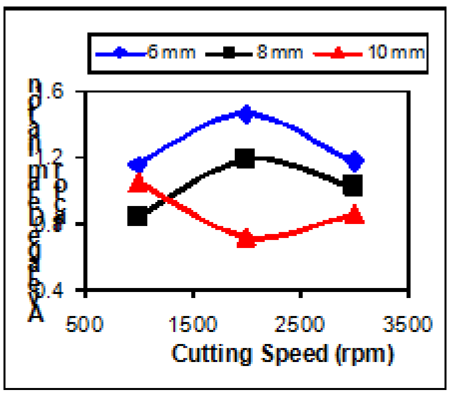

Figure 4. Average Delamination Factor vs Cutting Speed

B. Thrust force and Torque

Cutting forces are very useful for drill-wear monitoring, because these forces generally increase with tool wear. Thus, within the tool wear region, cutting forces provide good assessment of the tool condition. If the tool cannot withstand the increased cutting forces, catastrophic tool failure becomes inevitable. Consequently, tool life, which is a direct function of tool wear, is best determined by monitoring thrust force. Due to the thrust developed during drilling, many common problems exist. Some of the problem causes in drilling are fiber breakage, matrix cracking, fiber/matrix debonding, fiber pull-out, fuzzing, thermal degradation, spalling and delamination. The thrust force and torque developed in drilling operation is an important concern. Monitoring of thrust force and torque in drilling is needed for the industry. Fig. 5 and 6 shows the relationship between the cutting parameters, Thrust, Torque respectively.

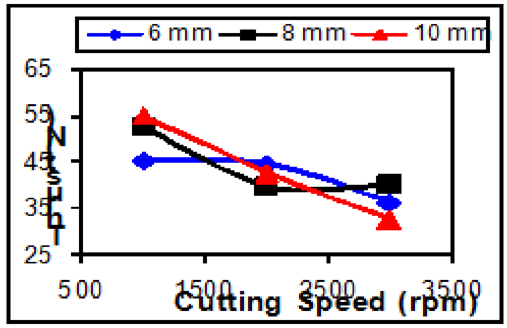

Figure 5. Thrust force vs Cutting Speed

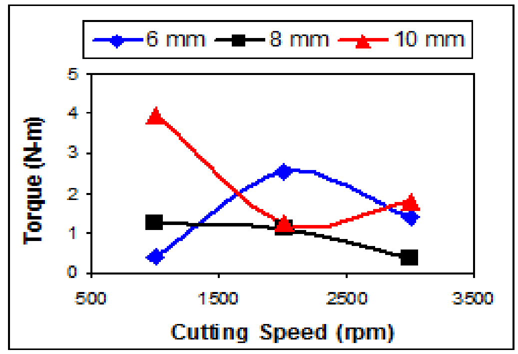

Figure 6. Torque vs Cutting Speed

C. Effect of Feed on Thrust force and Torque

In Fig. 7 and 8, the trend shows the effect of feed rate on Thrust force and Torque. The results in this figure indicate that increasing feed from 50-100 mm/min has significant effect on thrust force. For the drill size of 6 mm, thrust force was minimal at a medium feed of 75 mm/min. But at higher feeds, the thrust force was increased gradually. In the case of 8 mm drill, thrust force was well performed at higher and lower feeds, giving maximum thrust at medium feed. But in case of the 10 mm drill, the thrust force was gradually increasing from minimum to maximum feed as discussed by several authors. In case of Torque, the trend gave an insignificant effect on torque. In case of a 8 mm drill, the torque was reducing with elevated feed rates. But in the case of 6 mm and 10 mm drill, we can observe a gradual increasing trend of torque with increase in feed rate. Thus the feed rate influences the push down and peel up delamination next to material thickness. Therefore, the feed rate seems to be the most critical parameter and should be selected carefully for various drills for specific material thickness.

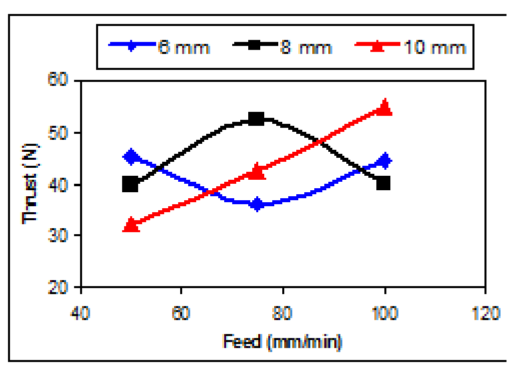

Figure 7. Thrust force vs Feed

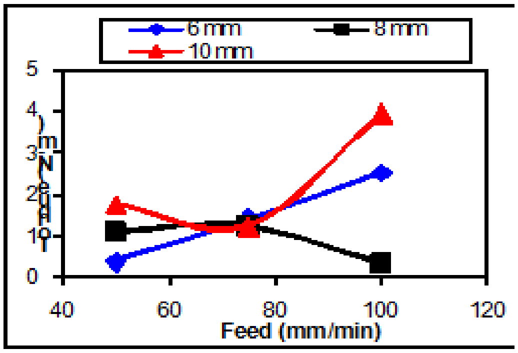

Figure 8. Torque vs Feed

D. Effect of Cutting parameters on Surface Roughness

Fig. 9 and 10 shows the Scanning Electron Microscope (SEM) images of the drilled hole laminate's wall. On comparing the effect of delamination factor, thrust force and torque, drill size of 8 mm with a speed of 3000 rpm and at a medium feed rate of 75 mm/min was regarded as the best cutting conditions to drill the Glass Fabric – Epoxy / Rigid polyurethane foam sandwich hybrid composite. While observing the worst condition to drill the composite, we derived the parameters to be as 10 mm drill with minimum cutting speed as 1000 rpm and maximum feed of 100 mm/min, where tool wear was measured to be maximum. The following SEM images support the above observation.

Figure 9. SEM Image of Drilled hole laminate of 8 mm drill at 3000 rpm and 75 mm/min feed

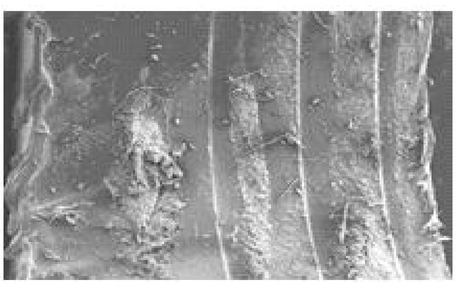

Figure 10. SEM Image of drilled hole laminate of 8 mm drill at 1000 rpm and 100 mm/min feed

E. Tool Wear

Tool wear study was performed for the worst drill. In this case, drill of 10 mm diameter was regarded as the most worn out tool in regard with the cutting conditions observed and the result derived from thrust force and torque corresponding to the cutting conditions. From Fig. 11 and 12 we can infer and support our result of tool wear for 10 mm drill. In Fig. 12, the image shows the crater wear. This wear was regarded due to the abrasion effect of the tool-work interface and was due to the excessive heat produced during drilling of the material which forms craters on the drill bit, thereby reducing the life of the tool

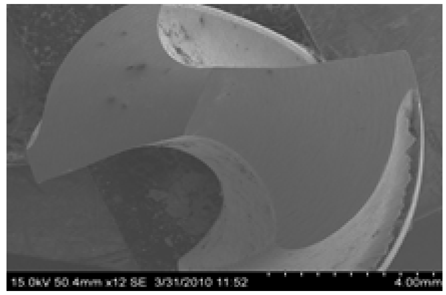

Figure 11. SEM Image of !0 mm drill with tool wear

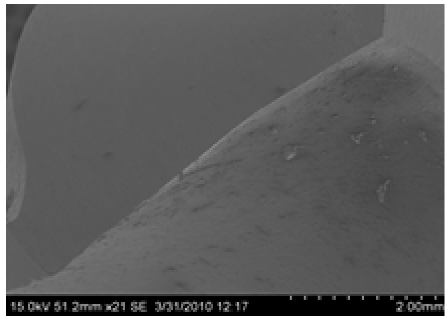

Figure 12. SEM Image of 10 mm drill with crater wear

CONCLUSION

The delamination factor of drilled Glass Fabric – Epoxy / Rigid polyurethane foam sandwich hybrid composite has been investigated and the results are given using the Design of Experiments. Important parameters such as Speed, Feed, Thrust and Torque responsible for delamination were studied. The following conclusions can be drawn from the investigation.

- The delamination factor depends on the spindle speed and feed rate, thrust and torque converges as the spindle speed is increased.
- Thus it is clearly seen that surface finish is good at medium speed and medium depth of cut.
- Thrust and torque are thus proved to be responsible for delamination along with speed and feed.
- The feed rate, cutting speed and material thickness are seen to make the largest contribution to the delamination effect.
- Generally, the use of medium and high cutting speed and medium feed favor the minimum delamination on both entry and exit of the drilling leads to better surface finish and tool life.
- The feed rate influences the push down and peel up delamination next to the material thickness. Therefore, the feed rate seems to be the most critical parameter and should be selected carefully.
- Varying the drill point geometry or drill point material for further results can do the next step in this study.

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